

T A
417
.2
B4
DOCS

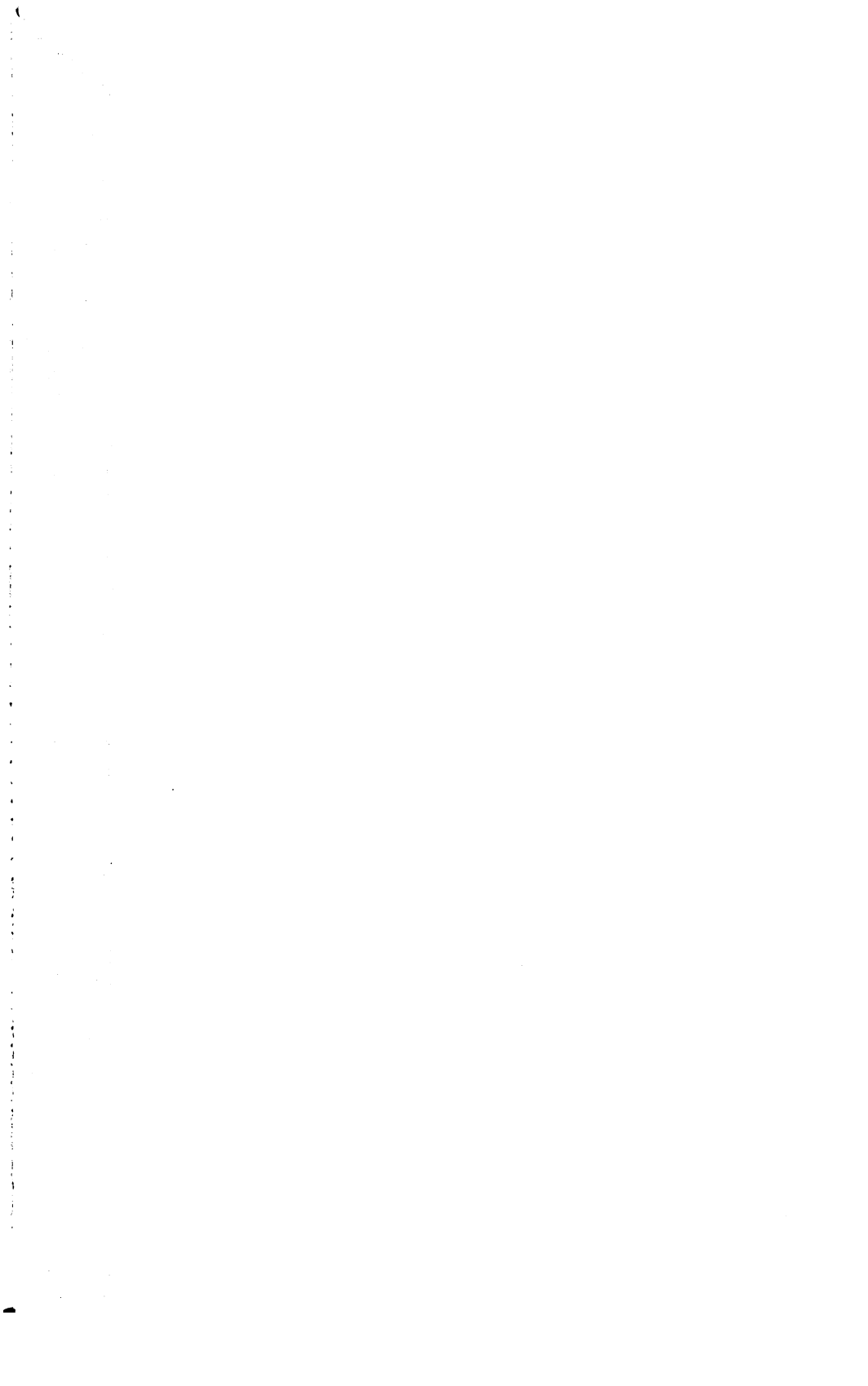
UC BERKELEY LIBRARY

UC-NRLF

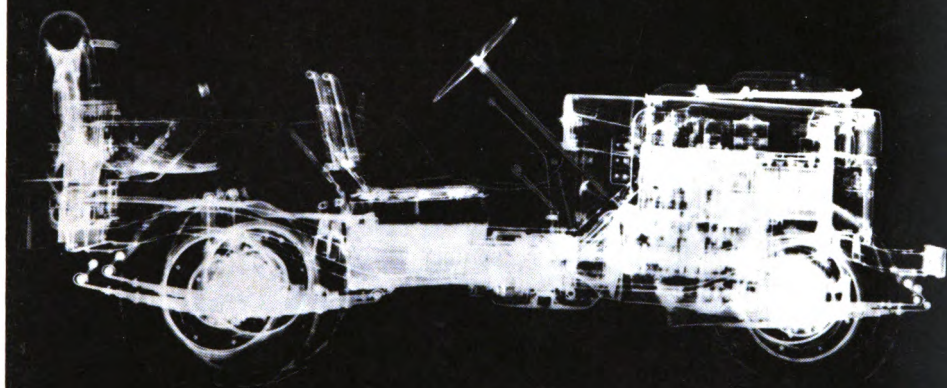


B 4 261 917

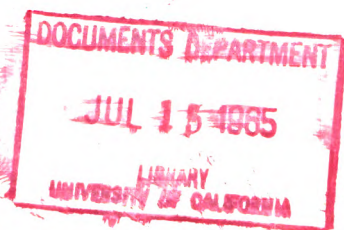




Nondestructive Testing



U.S. ATOMIC ENERGY COMMISSION / *Issued by* Division of Technical Information *Level 1000*



np
ONE
OF A SERIES ON
**UNDERSTANDING
THE ATOM**

UNITED STATES
ATOMIC ENERGY COMMISSION

*Dr. Glenn T. Seaborg, Chairman
John G. Palfrey
James T. Ramey
Dr. Gerald F. Tape
Dr. Mary I. Bunting*

Nuclear energy
is playing a vital role
in the life of
every man, woman, and child
in the United States today.

In the years ahead
it will affect increasingly
all the peoples of the earth.

It is essential
that all Americans
gain an understanding
of this vital force if
they are to discharge thoughtfully
their responsibilities as citizens
and if they are to realize fully
the myriad benefits
that nuclear energy
offers them.

The United States
Atomic Energy Commission
provides this booklet
to help you achieve
such understanding.

Edward J. Brunenkant
Edward J. Brunenkant
Director
Division of Technical Information

pl
Long

Nondestructive Testing CONTENTS

1	WHAT IS NONDESTRUCTIVE TESTING?
4	WHY IS NONDESTRUCTIVE TESTING USED?
7	PRESENT METHODS
11	PENETRATING-RADIATION TECHNIQUES
20	ULTRASONIC METHODS
27	PENETRANT TECHNIQUES
30	FUTURE PROSPECTS
36	SUGGESTED REFERENCES

66219437

Docs

THE COVER

X-radiograph of a jeep. This unusual radiograph illustrating industrial use of X rays for testing purposes is discussed in detail in the section of this booklet dealing with Penetrating-Radiation Techniques. This picture actually is a composite of many smaller radiographs.

Courtesy Eastman Kodak Co.

THE AUTHOR

HAROLD BERGER has been an Associate Physicist at Argonne National Laboratory since 1960, working with the Nondestructive Test Group of the Metallurgy Division. He has been concerned primarily with the development and application of neutron radiography and ultrasonic imaging methods. Previously, in an eight-year association with the General Electric Company, Mr. Berger was engaged in development of X-ray and light-detection systems.

Mr. Berger received his B.S. and M.S. degrees in physics from Syracuse University in 1949 and 1951. He is a member of the American Physical Society and the Society for Nondestructive Testing.

Nondestructive Testing

By HAROLD BERGER

TA417
.2
B4
DOCS

WHAT IS NONDESTRUCTIVE TESTING?

Drop a coin in the slot, pull the plunger, and reach down for your candy bar, cigarettes, or bottled drink.

Unless you're in the business of making vending machines—or slugs—you probably think little at such a time about the machine or the coin you drop into it. You may be surprised to learn that the machine subjects your coin to a great many tests, to assure its genuineness, before the product you bought is delivered.

The coin is tested for size, shape, and magnetic properties (and, in some machines, for its weight and elastic properties), all in the few seconds between the time you insert it and the time your purchase pops out.

These tests must be made quickly and in such a manner that the coin is still useful when the tests are finished. In this respect, the tests have much in common with many nondestructive tests made in industry.

Nondestructive testing, however, is not limited to industrial, medical, or scientific use but is something we all employ in everyday affairs. If, while drying the dishes at home, you drop a drinking glass or a plate and pick it up and look at it to determine if it is broken, you are applying a nondestructive test. If you do not see a crack or a broken spot, you probably will assume that the glass is undamaged and can continue to be used for its intended purpose. You

have not damaged it by looking at it; therefore your test was nondestructive.

If, on the other hand, you believe an invisible crack may have formed in the plate, and deliberately apply stress by trying to bend it against your knee, the test may not be nondestructive. If you apply too much force, the plate may break. If it does, it will no longer be useful for its intended purpose.

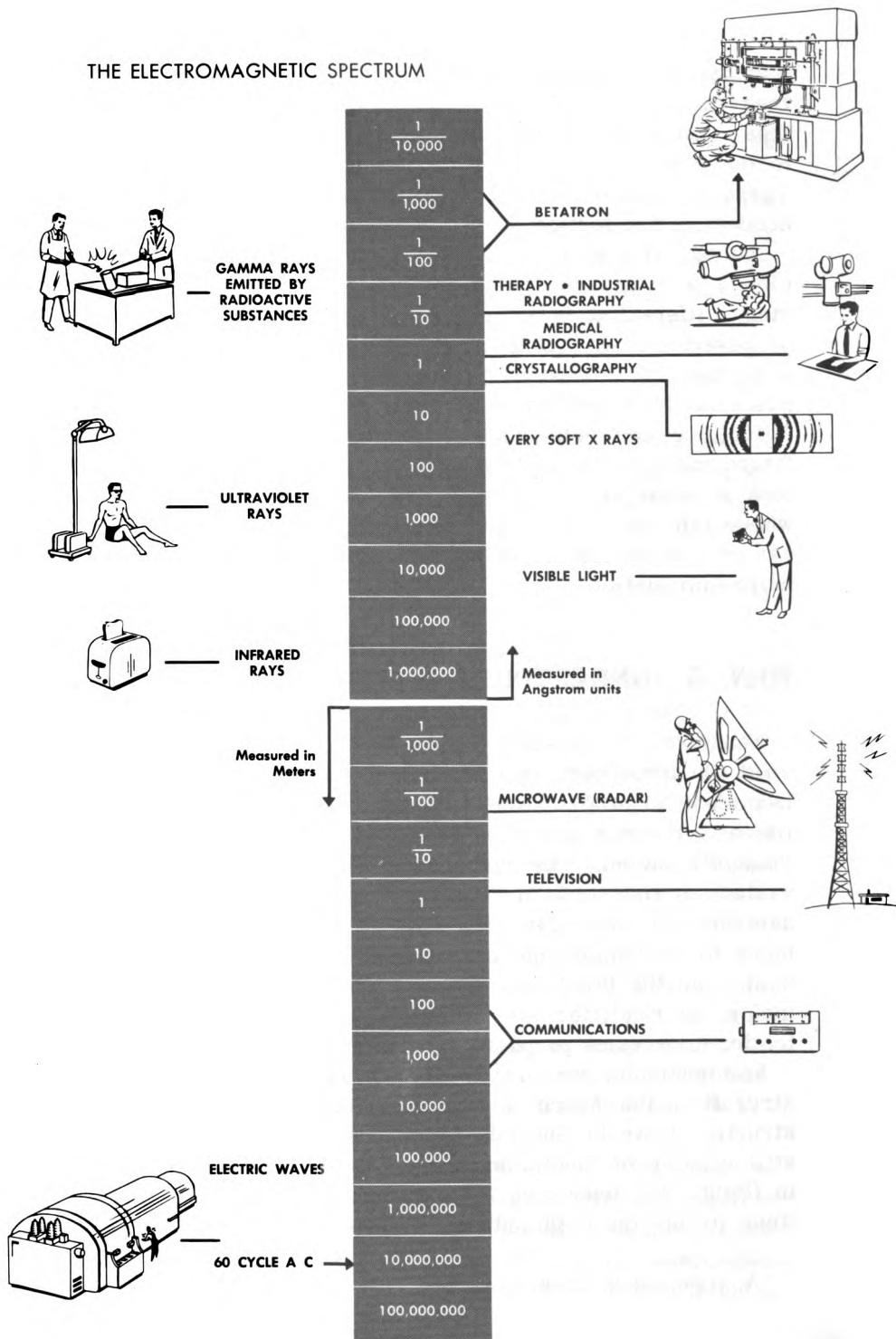
You and I, it is clear, daily apply tests, both destructive and nondestructive. In our discussion so far, you may have noticed the use of the phrase "for its intended purpose". This phrase is really the criterion for determining whether a test is destructive or nondestructive. For example, many people might think of X-radiography—the inspection of an object by obtaining a visible image of the X-radiation transmitted through the object—as a typical nondestructive test. For most cases this is certainly a valid assumption: X-radiography is a very widely used method of nondestructive testing. However, if we were to inspect a box of photographic film by this method, the test probably would *not* be nondestructive. The fogging caused by the X rays would doubtless make the film totally unsuitable "for its intended purpose"!

The requirement that the test leave the inspected object in a useful form is the essential element of our definition of nondestructive testing. Let us therefore describe a nondestructive test as being an examination of an object in any manner which will not impair the future usefulness of the object. The purpose of the examination may be to detect internal or external flaws, to measure thickness, to determine material structure or composition, or to measure or detect any of the object's properties. The test method may be a simple visual one, or it may involve some form of electromagnetic energy other than visible light, such as X rays, infrared rays, or microwaves. Figure 1 indicates some of the many forms such energy can take. The test

Figure 1 *The electromagnetic spectrum with some uses of various portions indicated by the drawings. The wavelength regions are indicated in Angstrom units (there are 10,000,000,000 Angstroms in 1 meter) in the upper part of the diagram and in meters in the lower part.*

Courtesy Eastman Kodak Company

THE ELECTROMAGNETIC SPECTRUM



may involve vibrational energy (sound) over a wide range of frequencies. The frequencies normally used encompass those above the audible limit of 20,000 cycles per second to those in the range of 10 to 20 megacycles* per second. These so-called ultrasonic vibrations are widely used in nondestructive testing.

Indeed, almost any physical phenomenon may be employed as a means of nondestructive testing, and a great many different ones actually have been used. It would not be possible or desirable to describe all these techniques in a booklet of this size. However, we can discuss a few basic methods and some of their characteristics. In addition, we can obtain some insight concerning possible future methods for nondestructive testing by taking a quick look at some of the methods now under study. For those whose interest in this subject may be stimulated, the suggested references at the end of this booklet can provide more information.

WHY IS NONDESTRUCTIVE TESTING USED?

Nondestructive testing principles and methods are being used when you pick up a dropped glass or plate to see if it is broken, when a shopkeeper drops a coin on the counter to listen to its ring, and when a shopper squeezes a tomato or thumps a melon. The purposes behind these tests are as varied as the tests themselves. The first was made to determine if the plate was still useful. The second was made to determine the composition, or genuineness, of the coin. And the third was made to see if the tomato or the melon was ready for use. Industrial uses of nondestructive testing encompass purposes similar to all these, and more.

For example, as in our visual inspection of the dish, aircraft maintenance workers perform periodic nondestructive tests to find out if components of an aircraft are still capable of functioning without the likelihood of failure in flight. We depend on tests to tell us if we should continue to use the dish and risk a messy table, and to advise

*A megacycle is 1,000,000 cycles.

us whether to continue to use the aircraft parts and risk a crash if they should malfunction or break. The effort expended in either test has a direct correlation with the risk involved.

The shopkeeper and his ringing coin bring to mind the significant industrial problem of sorting and identifying materials. Tests that can be used to sort metallic materials by means of magnetic or electrical properties are readily available and easy to interpret. Nevertheless, even today a number of product failures can be traced to the inadvertent use of the wrong material for some machine component.

It is somewhat more difficult to find an industrial counterpart for a tomato-squeezing shopper. The shopper makes her test to help her decide if the tomato is ready for use. She may be compared with the inspector who drives a just-finished automobile off the end of the assembly line to determine whether or not the car is ready for the consumer.

Actually we find nondestructive testing entering the production process well ahead of this last step and continuing even after the product leaves the factory. It is used to detect faulty material before it is formed or machined into component parts, to detect faulty components before assembly into the product, to measure the thickness of metal or other material, to determine the level of liquid or solid contents in opaque containers (from huge gasoline storage drums to beer cans), to identify and sort materials, and to discover defects that may have developed while the material was being processed or used.

These tests are used to make products reliable, safe, and more economical. Increased reliability, of course, also improves the public image of the manufacturer, a factor that leads to greater sales and profits. In addition, manufacturers use nondestructive testing to improve and control manufacturing processes.

A particular manufacturer may have any of several different motives for his initial investment in nondestructive testing. He may recognize advantages in using nondestructive tests in place of, or in addition to, destructive tests or proof tests. Typical destructive tests subject a

small percentage of a manufacturer's products to a force sufficient to destroy them, in order to determine the products' strength. On the other hand, proof tests subject *every* product to the maximum force the product might be expected to receive in use, to determine the percentage of failures.

Manufacturer A may find, from customer complaints or his own long-term tests on small samples of his output, that his product does not have the reliability which he would like or which may be required to meet his competition. Manufacturer B may find that his factory is wasting a great deal of time and money machining raw material that later is found defective and must be scrapped. Manufacturer C realizes that proper use of nondestructive testing in certain areas of production could help pinpoint improvements needed to lower production costs. In many cases, instead of costing more, nondestructive testing actually saves money by effecting manufacturing improvements.

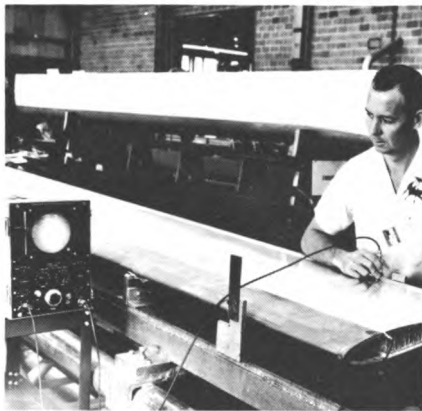


Figure 2 *Inspector using nondestructive ultrasonic test unit on helicopter rotor blade to search for possible areas where materials were not bonded together properly.* Courtesy Federal Aviation Administration

In the present era of nuclear reactors, high-performance military aircraft, and space flight, nondestructive testing plays an increasingly essential role (see Figure 2). Here the cost factor for the nondestructive test is of less importance than in consumer goods, since reliability is the prime requirement. For example, one of the U. S. moon shots was extremely successful in hitting its target, but the failure of the television equipment was a frustrating and costly malfunction. Improved testing might have pinpointed

the source of trouble in advance and saved not only the expense of another try but also time and effort for other aspects of the space program.

PRESENT METHODS

Now that we have an idea of the what and why of non-destructive testing, let us consider some of the methods. These methods vary a great deal in their complexities, in the amount of equipment they require, and in the type of testing they can perform.

Many nondestructive testing methods are related to our own senses. For example, X rays, infrared rays, microwaves, and similar radiations may be considered extensions of the sense of seeing, since all involve electromagnetic radiation and are therefore similar to light. Ultrasonic methods are associated with our sense of hearing because both make use of mechanical vibrations. Testing techniques for detection of surface and surface-connected flaws, such as penetrant techniques, may be associated with our sense of touch.

The senses themselves provide us with some important nondestructive tests, such as egg-candling (in which an egg is held to a strong light so that staleness or fertility can be detected visually) and the old sonic test for metal (in which parts were struck with a hammer and flaws detected by the sound of the ring). As you might suspect, the successful application of these tests often depends, however, on whether the inspector has slept well the night before. Today the trend is toward greater complexity and delicacy in testing methods because parts are more complex, because safety factors are more exact, and because, in space science and nuclear applications, the need for the utmost in reliability is paramount.

Fortunately manufacturers and engineers have a large number of proven methods from which to choose. This has not always been the case, however, for in the technology of nondestructive testing, as in other fields, progress has been great in the past 10 to 30 years. The multiplication of the basic testing methods and innovations in testing

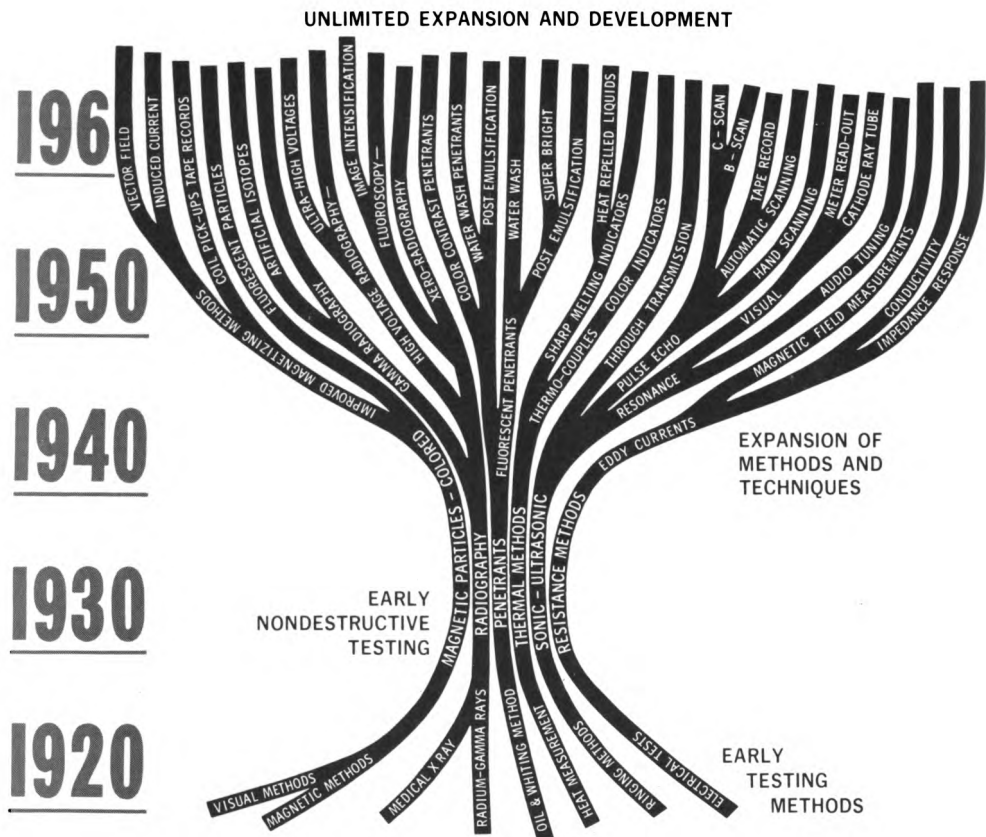


Figure 3 *The growth of nondestructive testing.*

Courtesy Magnaflux Corporation (reprinted with permission of the Society for Nondestructive Testing)

which have been made in recent decades is illustrated in Figure 3. Although many of the terms on this diagram may be unfamiliar to you, we will not attempt to discuss them all. Each of the branches on this tree, however, represents another method for nondestructive testing.

The growth of this tree of methods was very slow in the beginning. For example, X-radiation was discovered by a German physics professor, Wilhelm Roentgen, in 1895. Medical use of X-radiation was initiated in many parts of the world soon afterward. However, industrial use of non-

destructive testing lagged behind, receiving no significant support until after World War I. Nondestructive testing, in general, had no great impetus until World War II.

Although this seems surprising on first consideration, there were valid reasons for the delay. Before World War II, nondestructive testing was not urgent because of the large safety factors which typically were engineered into almost every product. Service failures did take place, of course; and railroad axles and crankshafts for rotating equipment, for example, did break in service despite large safety factors. However, the role of material imperfections in such failures was not then fully recognized, and therefore little concentrated effort was made to find them.

During and just after World War II, the significance of imperfections on the useful life of a product came to be more fully appreciated. In aircraft design, in nuclear technology, and, more recently, in space exploration, the factors of high hazards and costs have made maximum reliability vital. Moreover, the years since the war have witnessed a large growth of all inspection methods in industrial and scientific applications, where design and manufacturing specifications go hand in hand.

In spite of many differences, these methods have much in common because there are five basic elements in any nondestructive test.

First, a source is needed which provides some probing medium—a medium that can be used to inspect the item under test.

Second, this probing medium must change as a result of discontinuities or variations within the object being tested.

Third, a detector capable of detecting the changes in the probing medium is required.

Fourth, a means of indicating or recording the signals from the detector is necessary.

Fifth, some method of interpreting these indications must be provided.

Let us now see how these apply in the case of X-radiography. The source of the probing medium is the X-ray generator from which the radiation is emitted. The rays are modified as they are transmitted through the test specimen. The detector in this process normally is X-ray-sensitive photographic film. Darkening of the film provides an indication and a record of the test, and the interpretation usually is provided by a human observer.

These five basic elements—source, modification, detection, indication, and interpretation—are common to all nondestructive tests. Let's again use the glass dropped in the kitchen as an example. The source of the probing medium (light in this case) might be the sun or an electric lamp. The modification would be the manner in which the light was transmitted or reflected from various parts of the glass. A crack, for example, would reflect much of the light striking it. The detector would be the human eye, and the indications would be the varying amount of light returned to the eye by the glass. The interpretation in this case would, again, be provided by a human brain.

You may ask if any other method of interpretation is possible. The answer is yes. For example, thickness gauges that electronically compare an indication to some preset standard are in common use. Some of these, on equipment for rolling sheet metal, for example, even provide error signals that tell the rolling equipment to make the material thinner or thicker. Devices that check the level of fill in milk or juice containers usually are set to reject automatically the vessels not containing the specified amount. These are cases in which the testing device itself can provide the interpretation.

As you can see, such devices are practical primarily in high-production items where fast control is essential. In most cases, and certainly in those involving inspections of critical items such as reactor fuel elements, aircraft, or missile components, the interpretation still must be made by an experienced human observer. In order to do the most effective job, this observer must be aware of many of the basic principles involved in the test he is using. In the next few pages we will consider some of these principles.

PENETRATING-RADIATION TECHNIQUES

Penetrating radiation in nondestructive testing usually means gamma rays or X-radiation—short-wavelength electromagnetic rays capable of going through relatively large thicknesses of material. These radiations are used for nondestructive testing in science and in industry in the same way your dentist uses X rays to “look” through your teeth and gums for evidence of decay or disease. Before we discuss these methods in detail, we probably should learn more about the radiations.

These rays are, like light, infrared, or radio waves, a form of electromagnetic radiation, but, as shown in Figure 1, their wavelengths are much shorter.



Dental X ray.

It is this shorter wavelength which gives X rays and gamma rays the ability to penetrate materials with greater ease than their long-wavelength counterparts.

Gamma rays and X rays differ only in the sources from which they originate and in their wavelengths. Gamma rays usually have a nuclear origin. That is, gamma radiation is one of the types of radiation which can be emitted from the nucleus of an atom of a radioactive substance. X rays, on the other hand, usually are produced by a machine in which electrons are accelerated by high voltage and shot against a metallic target. They are nonnuclear in origin.*

A common source of gamma radiation used in nondestructive testing is the radioactive material cobalt-60. This gamma source can be obtained in various sizes and radiation intensities. Commonly, a radioactive pellet smaller than a dime is employed. The pellet is usually enclosed in some heavy container, which is opened only when an exposure, or test, is being made. The container provides shielding to protect persons near the source from the constant emission of the penetrating rays. The actual

*For more information on radiation and nuclear energy, see *Our Atomic World*, a companion booklet in this series.

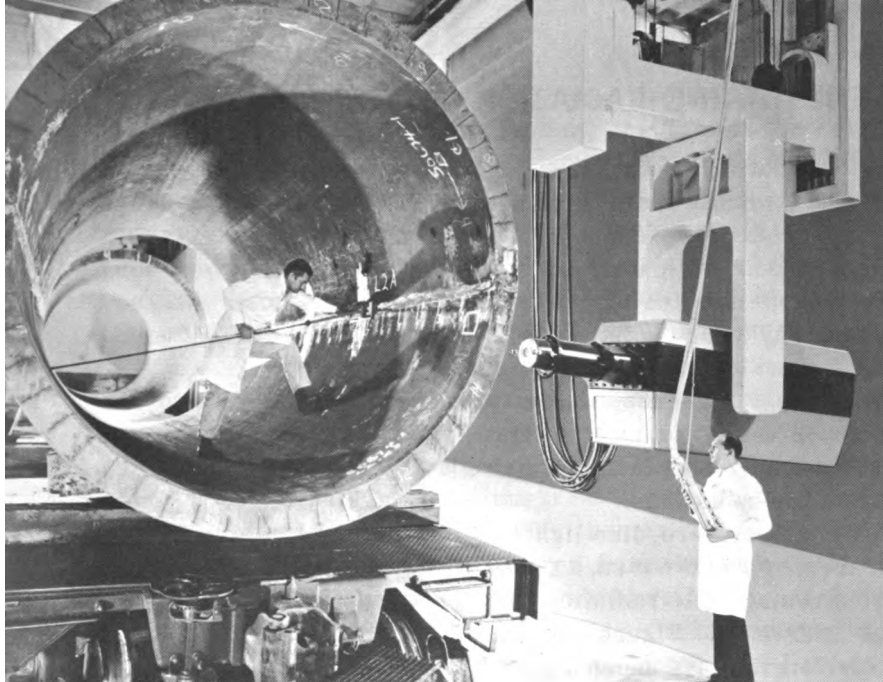


Figure 4 *An 8,000,000-volt linear accelerator X-ray source being set up to radiograph a weld in a large steel pipe.*

Courtesy High Voltage Engineering Corporation

size of the shield depends upon the intensity and type of source involved.

X-ray machines also come in a variety of sizes and shapes. The smaller machines, such as the one your dentist uses, usually operate at less than 100,000 volts. In industry, machines of this voltage are used to inspect the smaller thicknesses of light materials such as aluminum. To inspect heavier materials, such as steel, larger machines operating at higher voltages and producing X rays of shorter wavelength are necessary. Typical industrial machines operate at up to 300,000 volts and are used to inspect steel up to about 3 inches thick. (Even larger machines are available and are gradually becoming more common.) Accelerators and betatrons which can accelerate electrons to energies of 15 to 20 million volts are X-radiographic sources which are useful for inspecting steel many inches thick or other heavy materials (see Figure 4).

Not only gamma rays and X rays, but also electrons and neutrons are used in nondestructive testing. Electrons for

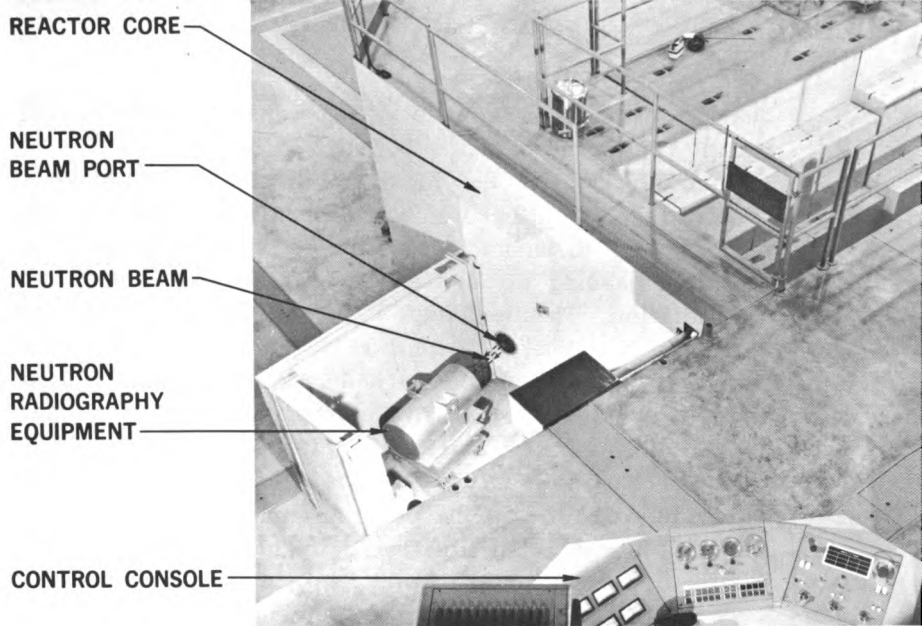


Figure 5 *The Juggernaut Research Reactor at Argonne National Laboratory. The device within the L-shaped wall next to the reactor is used for neutron radiography. This is one of many applications of the radiation from this reactor.*

Courtesy Argonne National Laboratory (reprinted with permission of the publishers of the International Journal of Applied Radiation and Isotopes)

these purposes are frequently produced by X-ray machines, by bombarding thin lead foil with X rays. Because they are easily absorbed, electrons are particularly useful for radiography of very thin or very light objects.

Neutrons can be obtained from a nuclear reactor, an accelerator, or a source of natural radioactivity. They too have special usefulness because of absorption differences between neutrons and X rays. For example, materials with high densities and high atomic numbers, such as lead and uranium, absorb an X-ray beam much more readily than materials with lower atomic numbers and densities. Therefore X-ray inspection of such materials usually requires generation equipment in the multimillion voltage range and relatively long inspection time. Neutrons, on the other hand, are easily transmitted through the heavier materials, and exposure time to complete the inspection can be appreciably shorter than that with X rays. A nuclear

reactor used as a source of neutrons for neutron radiography is shown in Figure 5.

Certainly one of the most commonly used methods of penetrating radiation for nondestructive testing is film radiography, a technique in which a visible image of the radiation passing through an object is produced on film by the radiation. This technique is so well established that the amount of X-ray film used for radiography is much greater than the total amount of black-and-white film used by all amateur photographers! The method typically used to make an X-radiograph is illustrated in Figure 6.

Notice how the X rays diverge from the target of the X-ray tube and cast a shadow of anything in their path. The flaw in the specimen illustrated might be a blowhole in a casting or a light metal impurity in some heavy material.

The radiation entering the specimen is absorbed less by the flaw than by the rest of the material, and therefore more radiation passes through to strike the film beyond the flaw than beyond the rest of the specimen. This would show up on the developed film as a dark area, revealing the presence, location, and general shape of the flaw.

The specimen in this illustration is nearly uniform in thickness and consistency except for the flaw area, but in many practical inspection situations this is not the case.

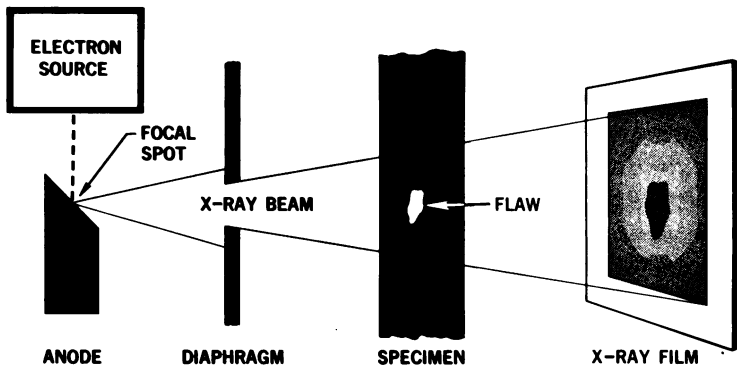


Figure 6 *Fundamentals of an X-ray exposure. The focal spot is the small area on the anode, or target, of the X-ray tube. The anode is bombarded by the electron beam in the tube. This spot is the source of the X-radiation. The X-ray intensity is decreased as the radiation passes through the thickness of the specimen.*

Just as we can see a flaw by a darkening of the X-ray film, we can also see changes in thickness or material. On the radiographs the dentist makes of your teeth, for example, the gums appear much darker than the teeth because the lighter materials in the soft tissue are less absorbing for the X-ray beam. Cavities appear dark within the shadow of the tooth because there is less material to absorb the radiation. Fillings, which contain heavy materials such as silver, are very absorbing and appear as light areas. (See dental X ray on page 11.)

Examine the radiograph of the jeep on the cover, for example, and associate the light and dark areas with the appropriate parts of the vehicle. The tires, for instance, which appear relatively transparent, were easy for the X-ray beam to penetrate, whereas the engine block was much more difficult. This is an unusual radiograph, both because the subject contains materials having a very wide range of radiation transparency and because of the large size (the picture is actually a composite picture of many smaller radiographs). (There are no lenses which can focus the X-ray image of a large object on a small piece of film as you do in your camera when you take snapshots.)

One question that naturally arises concerns the size of the flaws that can be detected by X rays. Suppose the flaw in the specimen in Figure 6 had been very small in the horizontal direction and had appeared no wider than the arrow leading from the word "Flaw". With normal X-radiographic methods it could still be detected if its thickness in the direction taken by the X-ray beam were about 2% of the specimen thickness in the same direction. Let's say, for example, that the specimen is a piece of steel 2 inches thick and that the flaw is a thin, flat, void area. Chances are that the flaw would be detected if it were at least 0.040 inch thick. If the thickness were appreciably less than that, as a typical crack would be, the difference in darkening on the X-ray film would be so small that the flaw might escape detection.

The detection of cracks by radiographic inspection is, therefore, not an infallible method. The crack either must be quite wide or must be positioned so that the radiation passes along its length for some distance. Inspection for

this kind of defect is usually done by other methods. In spite of this limitation, film radiography is broadly applied in nondestructive testing. One reason for its popularity is that the pictures which result are simple to interpret as compared with some other methods.

Penetrating radiation can be used in other methods of nondestructive testing also. Another imaging technique is fluoroscopy. In this technique the arrangement is similar to that for film radiography except that the film is replaced by a phosphor screen. The phosphor, when stimulated by X rays, emits visible radiation (light) of an intensity proportional to the X-ray intensity. Therefore the picture is like that obtained with film methods, except that the dark and the light areas are reversed.

Two related advantages of fluoroscopy are that there is no waiting for a film to be developed and that the object, therefore, can be moving while it is being inspected. Figure 7 shows a fluoroscope being used to inspect the contents of a suitcase.



Figure 7 *A portable package-inspection fluoroscope in use.*

Courtesy Westinghouse Electric Corporation, X-ray Division

Of course, there are also disadvantages. The observer must look at what is often a rather dim image in close proximity to the radiation area, and problems in lighting, radiation shielding, and operator fatigue are thereby presented. The shielding problem can be lessened by using lead-glass shielding windows and/or mirror systems to increase the distance between the operator and the radiation and to provide absorbing material to protect the operator. The radiation intensity can then be increased to provide improved image brightness. Electronic devices such as X-ray image intensifiers and closed-circuit television equipment can provide the ultimate solution to both the brightness and the shielding problems.

Although the use of fluoroscopic methods is increasing, the film method is preferred in many applications because it provides greater detail and somewhat better contrast (making observation of small changes in thickness or material possible) and because a permanent record of the inspection is automatically obtained.

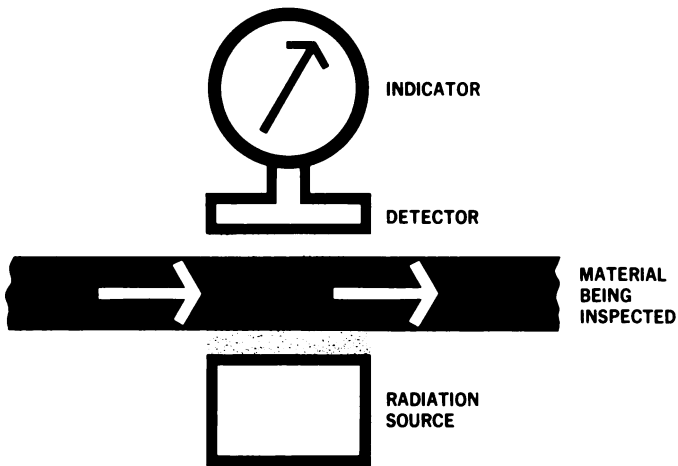


Figure 8 *A simple radiation thickness gauge. The radiation from the source is attenuated by the material being inspected. As the thickness increases, the radiation intensity reaching the detector decreases. If the response of the detector is calibrated for known thicknesses, the detector reading can be used to indicate the thickness of the inspected material.*

In addition to its use in radiographic and fluoroscopic techniques, penetrating radiation is often used where an image is not really needed to accomplish the desired result. For example, assume that you want to determine the level of the liquid within a large, opaque water tank. There are many ways you could do this. In one method you would make use of radiation, say from an X-ray machine or a radioactive source, on one side of the tank and a radiation detector on the other side. During the test you would move these from the top downward. A decrease in your detected signal would indicate that the radiation was going through the liquid to reach the detector. More of the penetrating radiation would be attenuated (thinned out) by the liquid than by the air above the liquid, and the change in the signal when the radiation moved from the air to the liquid would indicate the liquid-level line. The detectors in such applications include gas-filled counters that yield an electrical signal when the gas in the counter is ionized by the radiation, scintillation detectors that employ a combination

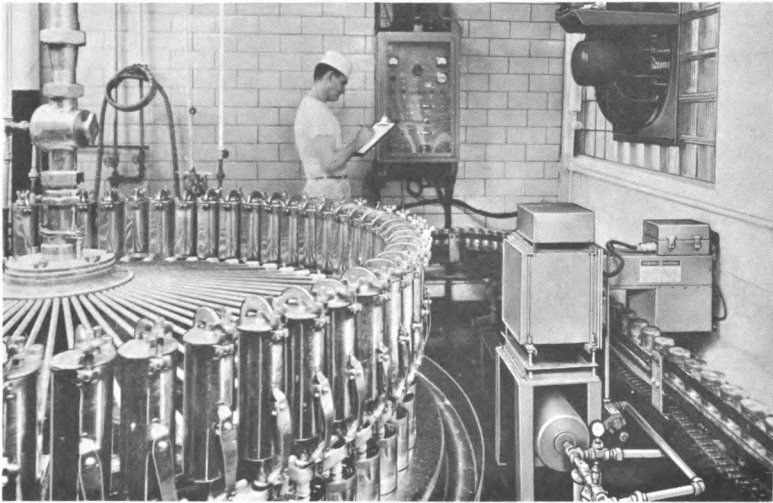


Figure 9 *An X-ray inspection system on a canned-milk production line. The X-ray unit and detection equipment bridges the can line at the right of the picture. With this equipment the cans are inspected at production-line speed for level of fill.*

Courtesy General Electric Company

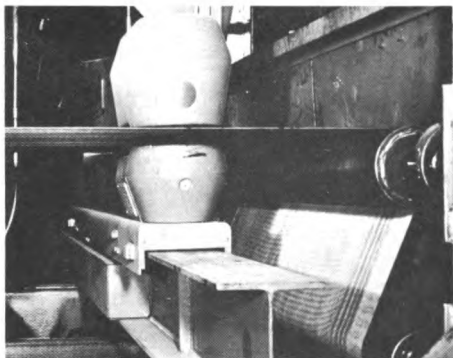


Figure 10 *A radiation gauge in use measuring sheets of rubber for tire casings.* Courtesy Dunlop Tire and Rubber Company

of a light-emitting material and a light detector such as a phototube, and photoconductive detectors whose electrical resistance changes with the intensity of the penetrating radiation.

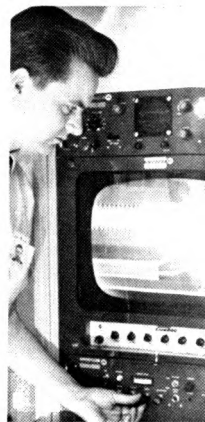
Such methods are used in many applications, including the determination of level in containers of juice, milk, and other liquids (Figure 9).

Changes in solid material can also be detected, even inside a container. This forms the basis of thickness gauges, which are widely used by manufacturers of metal, plastic, paper, and other sheet materials (Figure 10).

These are but a few of the many applications in nondestructive testing in which penetrating radiation has been successfully controlled and harnessed.

Figure 11 *X ray and television used in combination to give engineers direct viewing of radiographs. In view A, an employee places a part between X-ray tube (top) and television camera (bottom). In view B, he views television picture of another part. This system magnifies objects 27 times on the television monitor screen, and rotates so that objects can be viewed from all sides.*

Courtesy Atomics International Division,
North American Aviation, Inc.



ULTRASONIC METHODS

A very different nondestructive testing technique employs mechanical vibrations to discover useful information about materials (Figure 12). Sound is a good example. A vibrating tuning fork emits sound which travels through the air by alternately pushing and pulling the air molecules surrounding it. The sound wave is the continuation of these disturbances along a path in the air leading away from the vibration source. The alternate compression and rarefactions of the medium (air) produce a slight movement, or displacement, of the molecules in a direction parallel to the direction the sound is traveling. This type of wave is called a longitudinal wave.

Longitudinal waves can be produced which have frequencies higher than 20,000 cycles per second (which is about the upper limit of those we can hear), in which case they are called ultrasonic waves. Most ultrasonic non-destructive testing is done at considerably higher frequencies; a common range is 0.5 to 5 megacycles. Ultrasonic vibrations can be produced in several different kinds of waves, but in this discussion we'll consider only the longitudinal type.

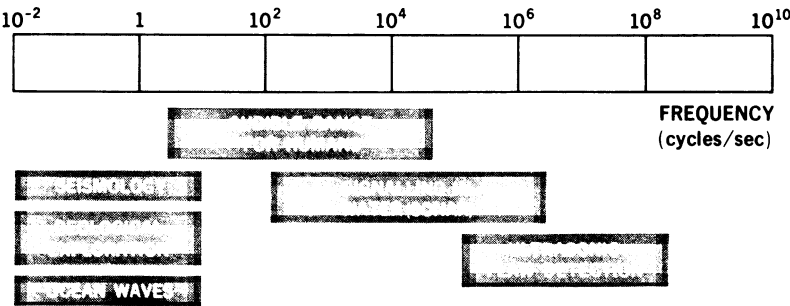


Figure 12 Mechanical vibrations.

This form of energy is very different from the electromagnetic energy we just discussed. Light, infrared, and X rays can travel through empty space, since they need no medium to support or propagate the wave motion. Sonic and ultrasonic waves, however, require a medium; since

nothing can be condensed and rarefied if nothing is there, there is no sound in a vacuum. These vibrational waves do have wavelengths, velocities, and other properties common to all wave motion.

Just as there is always some push or movement involved in the production of audible sound waves, so too there must be a similar effect produced by sources of ultrasonic waves. Ultrasonic waves for nondestructive testing are usually produced by piezoelectric materials. These are materials that undergo a change in physical dimension as they are subjected to an electric field. If we apply an alternating electric field to a slab of quartz, for example, the quartz will expand during the first half of the cycle and contract when the polarity of the electric field is reversed. By varying the number of times (or frequency) the alternating electric field becomes positive and negative, we can vary the frequency of the mechanical vibration produced in the quartz. Piezoelectric materials (quartz and barium titanate are common ones) are widely used as ultrasonic transducers.* They can convert electrical signals to mechanical signals and vice versa.

The property of these materials of generating an electric charge proportional to the mechanical pressure applied to them is known as "the piezoelectric effect". The opposite effect, mechanical movement proportional to the electric field, is known as the "reverse piezoelectric effect". Both are extremely important in ultrasonics because materials with these properties can be used not only to generate ultrasonic waves but also to detect them. In many practical testing applications, the same transducer serves both as a source and as a detector of ultrasonic waves.

Two common ultrasonic test methods, the through-transmission and the pulse-echo methods, are illustrated in Figure 13.

The through-transmission inspection method requires an ultrasonic transducer on each side of the object being inspected. If an electrical pulse long enough to contain

*A transducer is a device that converts input energy into output energy of another form. A microphone, as an example, converts sound into electricity.

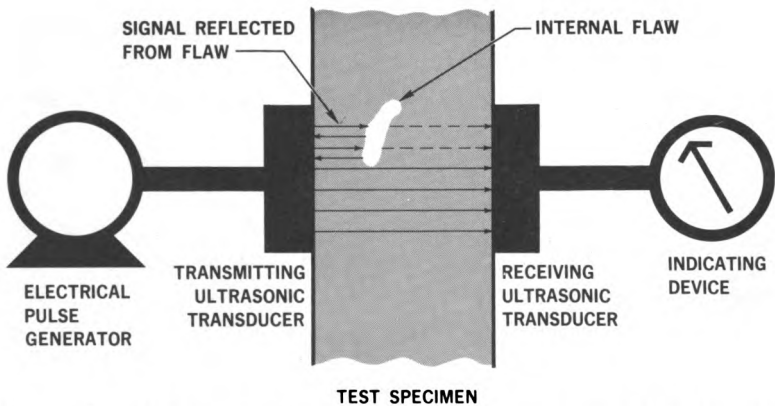


Figure 13 *Pulses of ultrasonic energy which cause vibrations to pass through an object can be used for inspection. A pulse of electrical energy causes the transmitting transducer to vibrate momentarily and the transducer sends its vibration pulse into the specimen. This will be received by a transducer on the opposite side. If there is a flaw in the path of the ultrasound, part of the energy will be reflected; a reflection signal will be received at the transmitting transducer, and the signal received by the receiving transducer will be reduced.*

several cycles of the desired frequency is applied to the transmitting crystal, the packet of ultrasonic waves produced will travel through the specimen to the opposite face. The second transducer, placed on the opposite side, receives the vibrations and converts them into an electrical signal that can be amplified and observed on the cathode-ray tube of an oscilloscope, a meter, or some other indicator. If the ultrasonic wave travels through the specimen without encountering any flaws or obstructions, the signal received is relatively large. If, however, a flaw is in the path of the ultrasonic wave, as in the diagram, the received signal is reduced and reveals the presence of the flaw.

The pulse-echo inspection method requires only one transducer, which serves as both transmitter and receiver. Note that a portion of the ultrasonic energy which encounters the flaw is reflected back to the transmitting transducer. This energy strikes the transducer and generates an electrical signal. The pulse-echo method of ultrasonic inspection makes use of this reflection signal. (This is also how sonar works.) The pattern on an oscilloscope for the pulse-echo inspection would look something

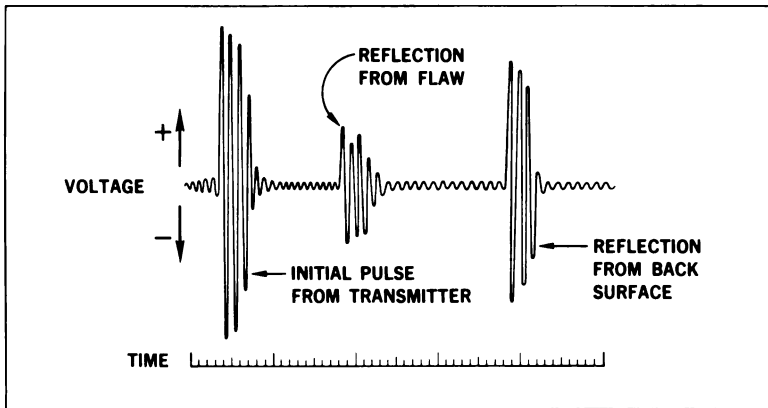


Figure 14 A typical voltage-versus-time graph of the signal on the transmitting transducer shown in Figure 13. The initial pulse to the transducer yields an indication, and the ultrasound vibration reflected from the back surface also returns to yield a voltage pulse. A reflected signal from a flaw is also shown. The distance of the flaw signal from the initial pulse is a measure of the distance of the flaw below the specimen surface. The size of the flaw voltage signal is an indication of the flaw size.

like that in Figure 14. There is an initial pulse of energy from the vibrating transducer. If the specimen is homogeneous, no ultrasonic energy returns to the transducer except on reflection from the back surface. If a flaw is present, a reflected signal appears between the initial pulse and the back-surface reflection pulse.

The reflection of an ultrasonic wave from a flaw or an interface is usually very large and can be thought of as similar to the reflection of light from a partially silvered mirror. Much of the light is reflected, but a small portion gets through. In the case of a metal-gas interface in a typical internal flaw in a metal specimen, only 10 to 20% of the ultrasonic energy enters the gas. The rest is reflected.

This fact, along with the fact that the reflected intensity is essentially uninfluenced by the width of the flaw, accounts for the excellent sensitivity of the ultrasonic method for the detection of cracks. This is true for both through-transmission and pulse-echo techniques, as well as other sonic methods, such as the resonance technique.

The resonance method differs from the other two in that continuous waves are used. That is, the ultrasonic trans-

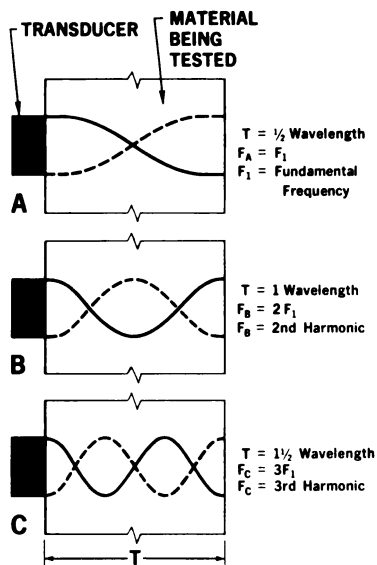


Figure 15 Conditions for ultrasonic resonance. The ultrasonic transducers send vibrations into the specimens. If the thickness (T) of the specimen is an integral number of half wavelengths, then the wave will reflect from the surface of the specimen in phase with the transmitted wave. That is, the crests of the reflected and transmitted waves reinforce each other. These strengthen each other and set up what is known as a standing wave. The frequency (F) increases as the wavelength decreases, and this gives rise to harmonics or resonances.

ducer is not subjected to an occasional pulsed electrical signal but is continually activated by an electrical signal. Instead of emitting energy in what would be equivalent to an occasional short toot on a whistle, the transducer in a resonance test emits the equivalent of a long steady blast.

The resonance method is illustrated in Figure 15. If the frequency of the ultrasonic waves sent into the test material is changed by varying the electrical frequency driving the transducer, a number of specific frequencies will each yield a detectable signal. If the thickness of the test object is an integral number of half wavelengths,* then the wave reflected from the back surface will be in phase with the oncoming wave. These strengthen each other and set up a standing wave that causes the test object to resonate.† Since this will also apply increased pressure to the transducer, this can be detected as an increased emerging electrical signal. Therefore, if we vary the frequency of

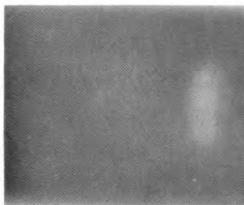
*A half wavelength is the distance between two successive minimums (antinodes) on the wave.

†When you sing in the shower, the sound waves of your voice may coincide with the resonance wavelength of the bathroom, which acts like a large organ pipe in this case and begins to “resonate”.

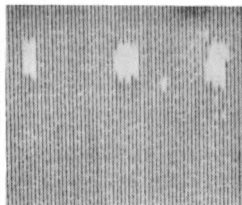
Figure 16 Comparison of three methods of nondestructive testing. The test object was an aluminum block, $1\frac{1}{8}$ inches thick, fabricated to contain several well-defined aluminum-air interfaces. Tests on this object included X-radiography, a mechanically scanned ultrasonic test, and the ultrasonic-image system. Results are shown in B, C, and D.



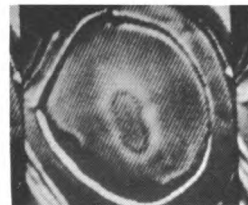
A. A diagram of the test object, top and side views. The three oval areas milled into the surface were $\frac{1}{4}$ by $\frac{1}{2}$ inch and 0.002, 0.005, and 0.010 inch deep.



B. An X-radiograph of this sample. The oval nonbond area 0.010 inch deep is clearly detectable; this indicates a thickness sensitivity of better than 1%. The other oval areas are not readily observed on the X-radiograph.



C. A copy of a recorder trace taken from a through-transmission test of the aluminum test block with a mechanically scanned, two-transducer ultrasonic device. All three oval nonbond areas are detectable, and good bonding is indicated in the remainder of the test object.



D. A print of a kine-scope motion-picture film (cinesonogram) taken during a test of the aluminum test block with the ultrasonic-imaging system. The image of one of the oval nonbond areas is clearly visible in the center of the frame. Each of the oval nonbond areas was clearly detected in a similar manner. (See Fig. 19.)

the transducer continuously and note the frequencies at which resonance occurs, we can easily find the thickness of the test sample (assuming that the velocity of ultrasound in that material is known).

Note that the value of the fundamental frequency can easily be determined by subtracting two successive har-

monic, or resonance, frequencies. The wavelength associated with this fundamental frequency is equal to twice the thickness of the specimen. The wavelength can be found from the relation

$$V = FW$$

where V is the velocity of the wave, F is the frequency, and W is the wavelength. The velocity, wavelength, and thickness should, of course, be expressed in the same distance units.

This technique for measuring thickness has the advantage that only one side of the material need be exposed. In addition, the resonance method can be used over a wide range of material thicknesses. Steel, for example, can be measured over a range from a few thousandths of an inch to several inches, with an accuracy as good as a few tenths of one percent.

On the debit side, the technique requires direct contact of the transducer with the measured material or contact through a conducting liquid. The fact that the method is responsive to internal flaws may also be regarded as a disadvantage in a thickness gauge. If there are a number of flaws, it may not be possible to obtain a thickness measurement because a standing wave cannot be set up; or, if a flaw happens to be oriented parallel to the surface of the specimen, a false thickness determination less than the actual value may be obtained. These disadvantages in thickness measurement do, however, make the method useful for flaw detection.

We have seen that these mechanical vibration techniques indicate flaws and are responsive to flaws much different from those we discussed in the section on radiation. Ultrasonic methods are preferred for the detection of cracks and for the inspection of bonding between two materials, which may amount to the same thing. The high sensitivity of the ultrasonic method in these uses, as well as in determining grain sizes and in detecting blowholes and other defects, helps account for its widespread use in nondestructive testing.

PENETRANT TECHNIQUES

Many defects in materials are not necessarily completely enclosed within the sample. For example, it is not unusual for a crack to originate on the surface of an object or to grow to the surface gradually from a stress point. In cases in which discontinuities are open to the surface, penetrant inspection methods can provide a simple and an effective means for discovering their location. These methods can be useful for inspecting any homogeneous material that is not porous. Therefore we find penetrant methods in wide use for testing metals, glass, plastic, and some ceramic materials.

A discussion of one or two types of penetrants will describe the basic method. Penetrants are usually light, oil-like liquids which are applied by dipping, spraying, or brushing, or in some other convenient manner. The liquid penetrant is drawn into cracks and other discontinuities by strong capillary action. After the penetrant has had time to seep in, the portion remaining on the surface is removed by wiping or washing. The test object is now changed because the penetrant is in all surface-connected discontinuities. If the penetrant can be made visible, it will reveal the location of all the surface openings. This is usually done by a process called developing. Typically this involves the application of a uniform fine powder on the surface. The developing powder acts like a sponge, drawing penetrant out of cracks and enlarging the size of the area of penetrant indication.

Of course, once the penetrant has been drawn out and spread in the developing powder, it must be easily observed for the inspection process to be completed. One desirable arrangement is for penetrant and developer to have contrasting colors or some other quality that will make the penetrant easily visible. Combinations such as white developers and red penetrants are common and readily provide penetrant indication.

Another common method is the use of fluorescent penetrants. In this case the penetrating liquid contains a material that emits visible light when it is exposed to ultra-

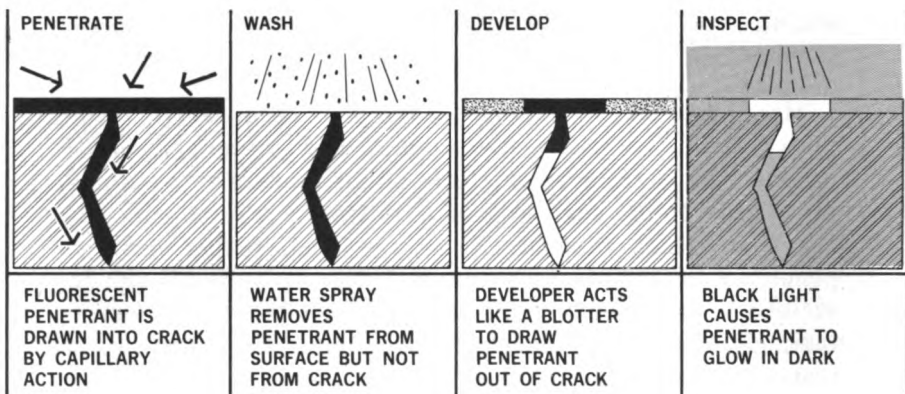


Figure 17 *Steps in fluorescent penetrant inspection.*

violet radiation, just as the phosphor screen in your television picture tube emits light when electrons strike it. Lamps that emit ultraviolet are called black lights because the visible light they might normally emit is stopped by a filter, making them appear black or dark purple. Fluorescent penetrant inspection is commonly performed in the dark, often in a cloth-darkened booth. When the inspector turns the black light on the part to be inspected, a defect appears as a bright fluorescing mark against a black background, an ideal contrast situation. The major steps of a fluorescent penetrant inspection are shown in Figure 17.

The visible- and black-light images of an aluminum helicopter-landing-gear part after penetrant inspection illustrate how the high contrast of the fluorescent-penetrant indication helps in locating even very small flaws (Figure 18). Tests have shown that these penetrants are capable of detecting cracks with surface openings as small as 10 one-millionths of an inch!

As you might expect, a great deal of "know-how" goes into the successful application of almost any nondestructive test. This is the case in the use of penetrants; and, although a few paragraphs of explanation will not transform you into a well-qualified penetrant inspector, we can at least explore the problems associated with this technique.

The part to be inspected must be clean. If the cracks or other surface faults are filled with grease or contaminants,

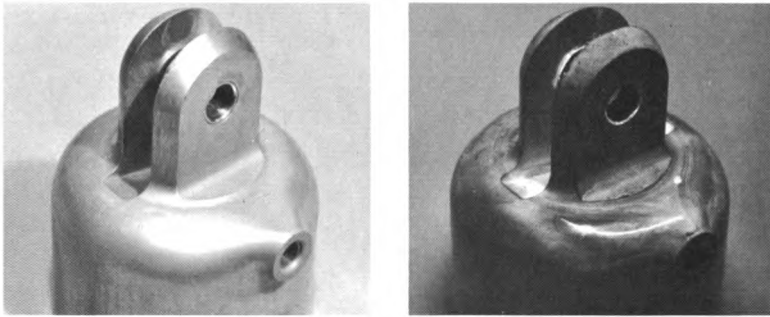


Figure 18 *An aluminum helicopter-landing-gear part after penetrant inspection. On the left is a white-light view of the part. On the right is a black-light view of the same part shown at left after fluorescent-penetrant inspection. The fluorescing crack is easily visible.*

Courtesy Magnaflux Corporation

the penetrant liquid may have difficulty entering, or the material in the crack may react with the penetrant, changing some of its properties.

Sufficient time must be given for the penetrant to seep into even the smallest flaw. This time varies with the material being inspected, the type of penetrant, and the kind of defect. It may vary from a few minutes to an hour. Experience is needed to decide.

Another critical area is the removal of excess penetrant. If all surface penetrant is not removed, many spurious flaw indications will appear after development. On the other hand, too much washing could remove penetrant from inside the discontinuities. Fortunately, some special penetrants are available to help with this, but even with help from improved products the know-how involved in this type of inspection is a significant factor for success.

There are, then, a number of problems involved in the use of penetrants, just as in any test. However, for the particular job of discovering surface-connected discontinuities, penetrants have advantages over other techniques. They can quickly and easily test large objects or many small ones at the same time.

There is no universally useful nondestructive test method that is readily capable of discovering all kinds of defects.

Because each method has some limitations, several non-destructive tests may be used on a single component to provide a complete inspection. There is a constant search for new methods that may show greater potential in certain applications.

FUTURE PROSPECTS

It is perhaps not surprising to find, in the investigation of new methods for nondestructive testing, that most so-called new methods really had their beginnings many years ago. For example, two techniques just coming into use can be traced back to the late 1930s. *Ultrasonic-imaging* methods were described by a Russian scientist, S. Sokolov, more than 25 years ago. A great number of patents testify to the efforts in that same period of a German research team, H. Kallmann and E. Kuhn, in the field of *neutron radiography*. In spite of the high quality of these early efforts, people were not quite ready to use these novel methods. The methods lay dormant until circumstances for their use were more favorable. In the case of neutron radiography, for example, wider use of the method had to wait until neutron sources were more plentiful.

Let's take a closer look at these methods. The words "ultrasonic imaging" seem to be a rather odd combination. We have already discussed ultrasonic techniques, and it may be difficult to see how ultrasonics is connected with imaging. The imaging technique is somewhat analogous to the radiography technique. Essentially, sound waves are used as light waves. Methods were sought for producing an image of the ultrasonic radiation passing through or reflected from an object, because a picture is easier to interpret, in many cases, than conventional ultrasonic indications. Many techniques for producing and displaying ultrasound pictures have been devised.

The main features of one ultrasonic imaging system using television are shown in Figure 19. The object to be inspected is placed in front of the camera tube of this closed-circuit television system. The ultrasonic radiation that passes through the object is detected by this camera,

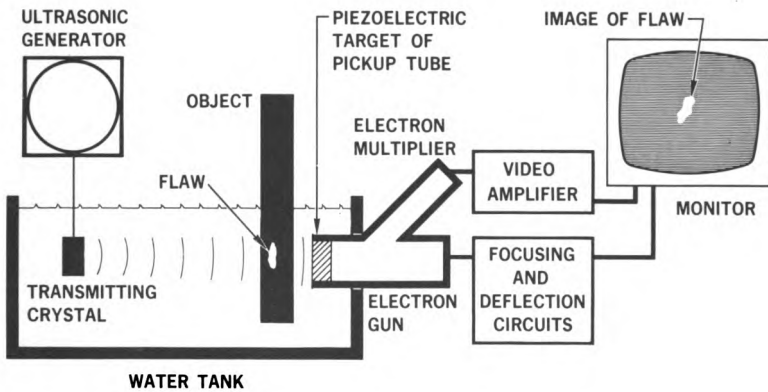
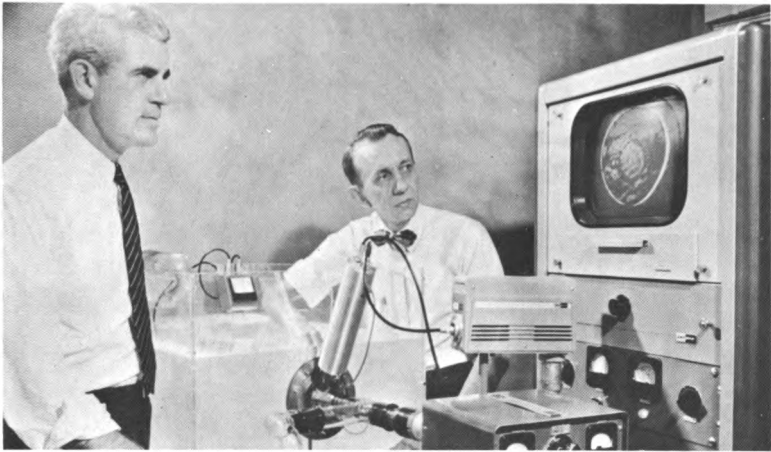


Figure 19 *Photograph and diagram of an ultrasonic inspection system that yields a televised picture of the ultrasonic radiation reaching the pickup tube detector. Water is used to transmit the ultrasonic vibrations in a flashlight-type beam from the transmitting crystal (left) to the object and then to the detector. This detector is a camera in a closed-circuit television system.*

Courtesy James Electronics, Inc.

or pickup tube, and the image is displayed on a television screen. This camera (like most television cameras) makes use of slight charge-density changes over the target area of the tube to produce the video, or picture, signal. These charge-density variations, which must correspond to the

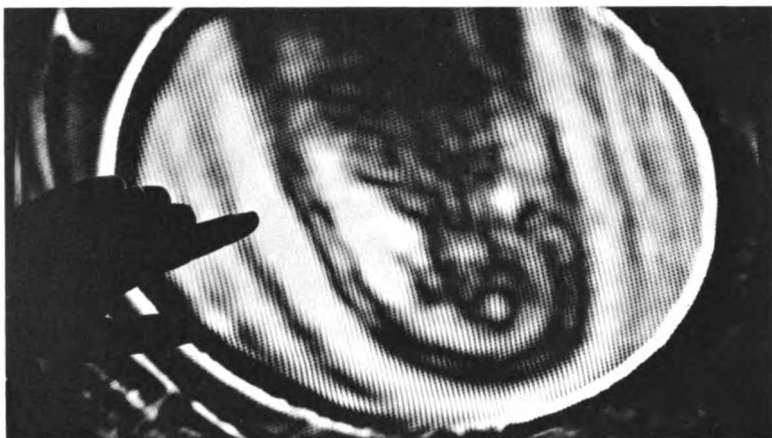


Figure 20 *Television picture of a human finger obtained with the ultrasonic system shown in Figure 19. The image of the finger is the oval in the center of the round white area, which is the image of the sensitive part of the television camera tube. The tip of the bone in the finger is easily seen. The hand at left points to the television image.*

Courtesy Northwestern University

image information, are produced in the ultrasonic cameras by a piezoelectric-target material. Piezoelectric materials develop a voltage that is proportional to the push, or intensity, of the ultrasonic wave. Moreover, these materials act as though they were made of small, independent elements, each of which develops a voltage corresponding to the ultrasonic intensity at that point, and this quality makes a video signal possible.

Ultrasonic imaging methods are useful, generally, for detecting the same types of flaws as those recommended for conventional ultrasonic tests. The inspection information is merely presented in a different manner, which may be more useful.

The imaging technique is being studied in several medical and biological laboratories as well as in industry. Ultrasonic methods are already used extensively in the medical field, and the image presentation is being investigated to see what advantages it may have. Among promising developments is its possible use in studying the movement of fluids in the body, particularly in the heart. Motion studies must be made by motion pictures or magnetic-tape

recording, because a still picture gives only a limited amount of information. An ultrasonic image of a finger tip is shown in Figure 20.

Neutron techniques, as we have already seen, are useful for inspecting heavy materials. In addition, they offer advantages in several other areas. For example, neutron inspection of neutron shielding or control materials for nuclear reactors has an obvious advantage. These materials are supposed to absorb neutrons. The use of neutrons to inspect them gives answers directly to the important question: Will they absorb neutrons properly?

Neutrons are also useful for inspecting highly radioactive materials. X-radiography usually has been used to inspect these substances. However, since the film that detects the X rays is also sensitive to the radiation from the radioactive material, considerable shielding and quick film movements normally are needed to minimize this disturbing effect. Even these measures are of little help if the object is highly radioactive. Neutron-created images, on the other hand, can be detected without exposing film, and so there is no problem with film fogging.

The neutron image can be detected by a sheet of metal, one especially chosen because of its tendency to become radioactive upon neutron irradiation. Metals such as indium, silver, and gold are commonly used. If a neutron beam passes through the object to be inspected and then strikes the metallic detector, the detector becomes radioactive. Moreover, it has been "imprinted" with a radioactive image of the neutron beam that passed through the object, since the radioactivity of the detecting sheet is directly proportional to the intensity of the neutrons at any point. The radioactive image on the detector can be made "visible" by placing it in contact with a sheet of film, which is exposed by the radioactivity in the detector. The film then can be developed in the usual way. This neutron image of a pocket flashlight (Figure 21) illustrates something of the detail that can be obtained by this method and also some of the differences between neutron and X-ray transmission in common materials.*

*For other examples of neutrons at work, see *Neutron Activation Analysis* and *Research Reactors*, companion booklets in this series.

Both these methods, neutron radiography and ultrasonic imaging, are in only the beginning stages of application, and both appear to have a number of uses for which they are particularly valuable: For the former, it is in inspection of radioactive materials and heavy metals, and for the latter, in fast, reliable, readily interpreted flaw detection. There are many other promising developments in non-destructive testing research involving not only new methods but also improvements on methods already in use. Infrared, microwave, and electrical techniques, such as eddy-current methods—these and even such old standbys as X-ray and ultrasonic inspection—are all being considered in interesting and potentially useful new developments. Experience has taught us that new techniques are necessary if the capabilities of nondestructive testing are to meet the demands that will inevitably be placed on them.

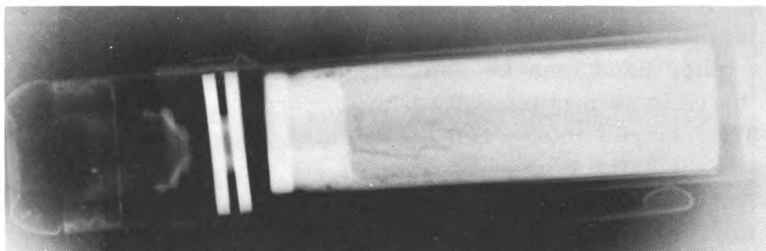


Figure 21 *Neutron radiograph of a pocket flashlight. Dark areas are regions in which the neutrons were easily transmitted. The white areas are those in which only a few neutrons penetrated. Those two vertical white bars are plastic disks that make up the on-off switch. The presence of hydrogen accounts for the high attenuation of the neutrons in this material.*

Courtesy Argonne National Laboratory

Nondestructive testing, you recall, is an examination of an object in any manner which will not impair future usefulness of the object. It is not surprising that many of the methods used to inspect metals, plastics, and other industrial materials also are being used in the medical field. After all, medical use often involves purposes similar to those of industry, including the detection of cracks, location of foreign material, or disclosure of other abnormal

inhomogeneities. Certainly in medical applications the term "nondestructive" is of particular importance.

Just as you would earnestly prefer to have a doctor X-ray your arm to find a broken bone than cut it open to search for the break, industrial people, too, prefer testing methods that do not destroy or impair the object. The advantage is obvious; the railroad axle, the landing-gear cap, or even the dropped dish can be used with confidence if the test results are satisfactory.

As you have gathered, any one nondestructive test usually is capable of yielding useful information about only some types of inhomogeneities. It is therefore common to test a component of an important assembly, such as a missile or a reactor, with a variety of methods. When a component comes through such a series satisfactorily, it can be used with the confidence that it will perform as intended. This high degree of reliability is, after all, the ultimate aim of nondestructive testing, an aim that makes all the effort worthwhile.

SUGGESTED REFERENCES

Books on Nondestructive Testing (General)

- Nondestructive Testing for Management*, American Society for Metals, Metals Park, Ohio, 1963, 68 pp., \$3.60. A collection of magazine articles based on a nondestructive testing seminar for supervisory personnel.
- Progress in Applied Materials Research*, E. G. Stanford, J. H. Fearon, and W. J. McGonnagle (Eds.), Heywood & Co., Ltd., London, volume 4, 1964, 246 pp., 70 shillings. A group of relatively long articles on various nondestructive testing methods. Previous books in this series were published by the Macmillan Company, New York, and entitled *Progress in Non-Destructive Testing*, volume 1, 1958, 267 pp., \$12.00; volume 2, 1960, 250 pp., \$12.00; volume 3, 1961, 227 pp., \$12.00.
- Nondestructive Testing*, W. J. McGonnagle, McGraw-Hill Book Company, Inc., New York, 1961, 455 pp., \$16.75. This book covers the fundamental principles of most nondestructive testing methods; it is a college-level text.
- Techniques of Non-Destructive Testing*, Cyril A. Hogarth and Jack Blitz (Eds.), Butterworth & Company, Ltd., London, 1960, 224 pp., \$7.50. A collection of lectures (college level) on varied topics associated with nondestructive testing.
- Nondestructive Testing Handbook*, R. C. McMaster (Ed.), The Ronald Press Company, New York, 1959, 1850 pp. (2 volumes), \$24.00. A complete text on all phases of nondestructive testing.

Books on Specific Methods of Nondestructive Testing

- Fundamentals of Ultrasonics*, Jack Blitz, Butterworth & Company, Ltd., London, 1963, 214 pp., \$6.95. A general text on ultrasonics written for the undergraduate physics student.
- Principles of Penetrants*, C. E. Betz, Magnaflux Corporation, Chicago, Illinois, 1963, 442 pp., \$7.35.
- Ultrasonic Technology*, R. G. Goldman, Reinhold Publishing Company, New York, 1962, 320 pp., \$11.00. A nonmathematical approach to ultrasonics.
- Radiography in Modern Industry*, Eastman Kodak Company, Rochester, New York, 1957, 137 pp., \$5.00.
- Sonics*, T. E. Hueter and Richard H. Bolt, John Wiley and Sons, Inc., New York, 1955, 456 pp., \$10.00. A book on ultrasonics written for the student or engineer who is not familiar with the subject.
- Applied X-Rays*, G. L. Clark, McGraw-Hill Book Company, Inc., New York, 1955, 843 pp., \$12.50. A college-level text in the field of X-radiation.
- Ultrasonics*, B. Carlin, McGraw-Hill Book Company, Inc., New York, 1960, 309 pp., \$11.50. This book on ultrasonics leans to the practical side.
- X-Rays in Practice*, W. T. Sproull, McGraw-Hill Book Company, Inc., New York, 1946, 615 pp., \$6.00. A basic text in all areas of X ray.

Booklets

- The Story of X-Ray*, General Electric Company, Milwaukee, Wisconsin, 1963, 62 pp., \$1.00. Discusses the history and principles of X rays.
- Radiography*, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., catalog no. FAA 5.11:4, 1959, 37 pp., \$0.35.
- Industrial Radiography*, Gavaert Photo-Producten N. V., Mortsel-Antwerp, Belgium, available from The Gavaert Company of America, Inc., 275 North Street, Teterboro, New Jersey, 1961, 100 pp., free.
- Safe Handling of Radioisotopes in Industrial Radiography*, Picker X-Ray Corporation, White Plains, New York, 1962, 53 pp., \$1.50.
- What You Should Know About Ultrasonic Search Units*, Sperry Products, Danbury, Connecticut, Technical Data Brochure 50-798, 1963, 16 pp., free.
- Visible Penetrant Process—Procedures and Techniques*, Met-L-Check Company, 11919 S. Western Avenue, Los Angeles 47, California, 1962, 8 pp., free.
- Quality Control in Japan*, Japan Trade Center, 393 Fifth Avenue, New York, 1962, 16 pp., free. Describes Japan's efforts at developing improved testing and inspection procedures.
- Bonding Inspection*, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., catalog no. FAA 5.11:5, 1960, 48 pp., \$0.40. Part of a series of quality control digests for the Federal Aviation Agency.

Articles

- ADVANCES IN FIELD EMISSION, W. P. Dyke, *Scientific American*, 210: 108 (January 1964). Detailed description of a special radiographic technique.
- ASSURING QUALITY, E. G. D. Paterson, *International Science and Technology*, 21: 33 (September 1963). A general discussion of testing and control techniques.
- INFRARED, J. King, T. Limperis, J. Morgan, F. Polcyn, and W. Wolfe, *International Science and Technology*, 16: 26 (April 1963). A report of numerous applications and potentials of this form of electromagnetic radiation.
- KILOMEGACYCLE ULTRASONICS, K. Dransfeld, *Scientific American*, 208: 60 (June 1963). Applications of high-frequency ultrasound are explained.
- NONDESTRUCTIVE TESTING, Warren McGonnagle and Ford Park, *International Science and Technology*, 31: 14 (July 1964). A discussion of theory and various methods including eddy-current testing.
- NEUTRON RADIOGRAPHY, Harold Berger, *Scientific American*, 207: 107 (November 1962). A description of this process giving the neutron-absorption capacity of many of the elements.
- ULTRASONIC IMAGE CONVERTER, Joseph Powers, *Research and Development Magazine*, Vol. 14: p. 24 (November 1963). Efforts to use ultrasonic viewing systems as an analytic tool are described.

- ULTRASOUND IN INDUSTRY, R. G. Neswald, *International Science and Technology*, 26: 28 (February 1964). A detailed, well illustrated report of this method.
- UNDERWATER SOUND, R. A. Frosch, *International Science and Technology*, 9: 40 (September 1962). Details of this method are given.
- X RAY, Jack Star and James H. Karales, *Look*, 28: 30 (June 1964). Medical use of X ray is explained.

Motion Picture

Available for loan without charge from the AEC Headquarters Film Library, Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C., and from other AEC film libraries.

Testing for Tomorrow, 30 minutes, sound, black and white, 1964.

Produced by David McElroy. Discusses general nondestructive testing methods in use at Argonne National Laboratory and indicates the high points of methods under development.

This booklet is one of a Series entitled "Understanding the Atom." Comments are invited regarding this booklet and others in the Series. These comments should be sent to the Division of Technical Information, U. S. Atomic Energy Commission, Washington, D. C., 20545.

The following booklets in the Series have been published:

SYNTHETIC TRANSURANIUM ELEMENTS	PLUTONIUM
FOOD PRESERVATION BY IRRADIATION	RARE EARTHS
NUCLEAR TERMS, A BRIEF GLOSSARY	ATOMIC FUEL
FALLOUT FROM NUCLEAR TESTS	ACCELERATORS
DIRECT CONVERSION OF ENERGY	OUR ATOMIC WORLD
NEUTRON ACTIVATION ANALYSIS	NUCLEAR REACTORS
CONTROLLED NUCLEAR FUSION	RESEARCH REACTORS
MICROSTRUCTURE OF MATTER	ATOMIC POWER SAFETY
POWER FROM RADIOISOTOPES	ATOMS IN AGRICULTURE
ATOMS AT THE SCIENCE FAIR	WHOLE BODY COUNTERS
CAREERS IN ATOMIC ENERGY	NONDESTRUCTIVE TESTING
NUCLEAR POWER AND MERCHANT SHIPPING	
POWER REACTORS IN SMALL PACKAGES	
POPULAR BOOKS ON NUCLEAR SCIENCE	

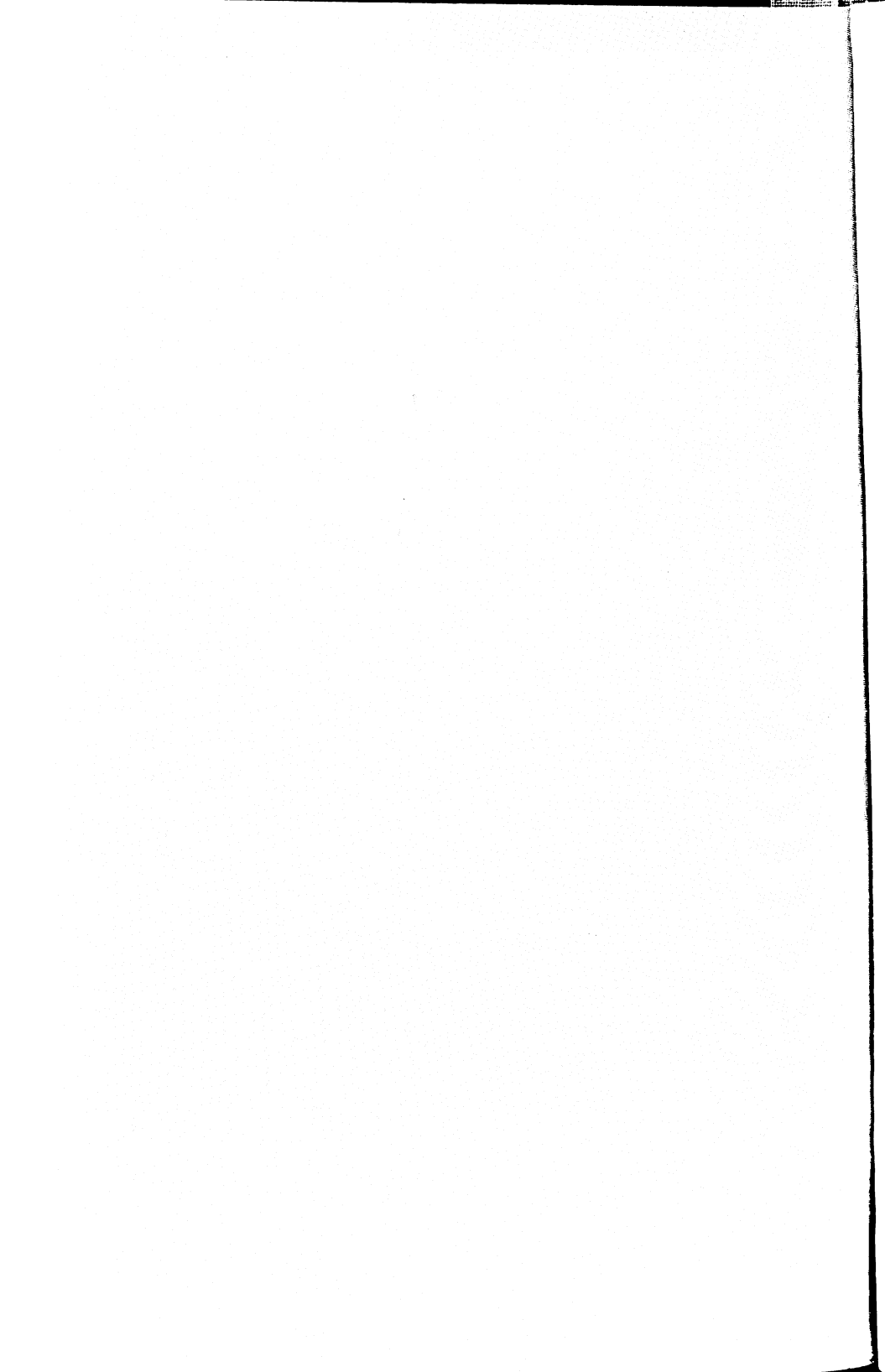
Single copies of these booklets and similar educational materials may be obtained free by writing:

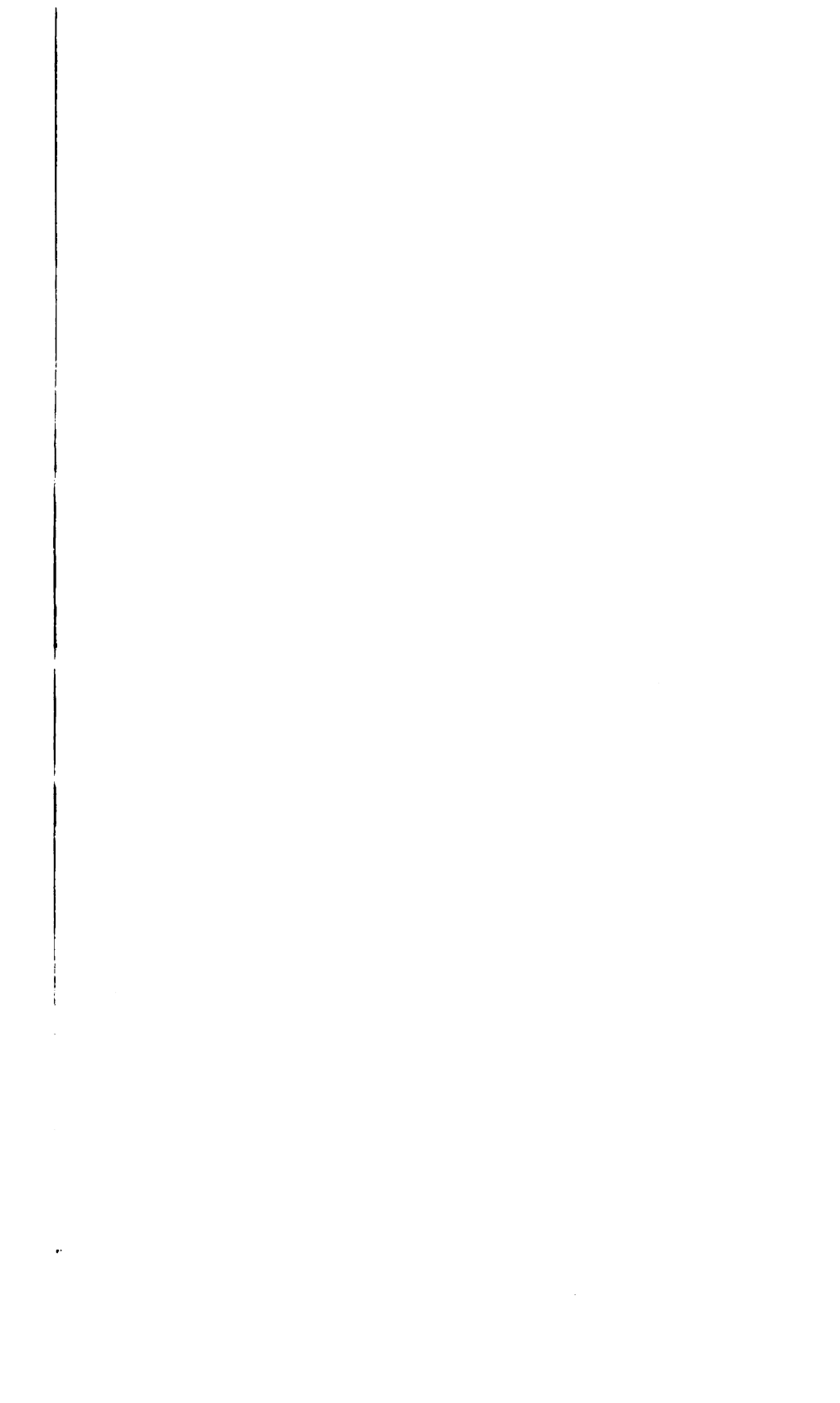
USAEC, P. O. BOX 62, OAK RIDGE, TENNESSEE 37831

Requests should indicate the specific topic of interest and the proposed use of the material desired.

Printed in the United States of America

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee
April 1965





U.C. BERKELEY LIBRARIES



C025206584

